SPCTOR:
Sensing-Policy Controller and OptimizeR

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Earth Science Technology Forum
10 June 2021

Background:

1. Soil moisture is highly variable across the land-scape and in time.
2. Landscape heterogeneity is integrated within observation footprint.
3. Observation architectures for soil moisture need to be spatiotemporally adaptive.
4. Distributed wireless sensor networks (WSNs) will increase <u>representativeness.</u>

   Yet, traditional WSNs are "**static.**"

   - Network deployment must consider different factors (topography, land cover, etc.)
   - Sensor networks that adequately measure heterogenous landscape soil moisture are currently limited

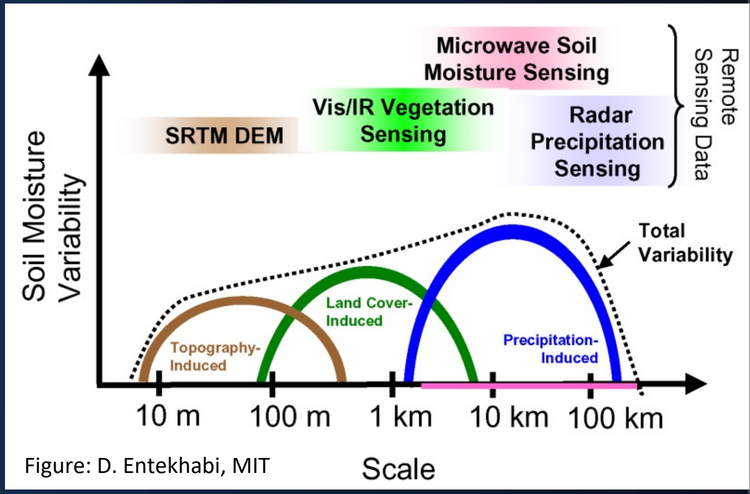
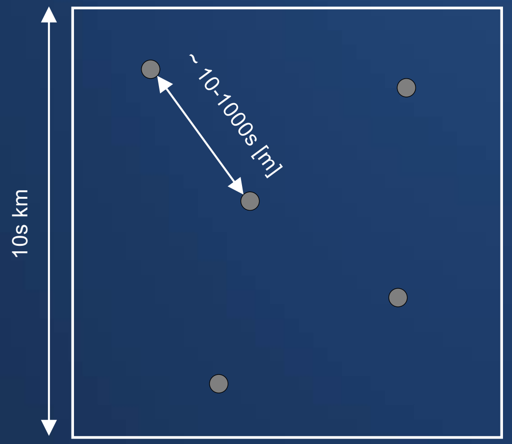
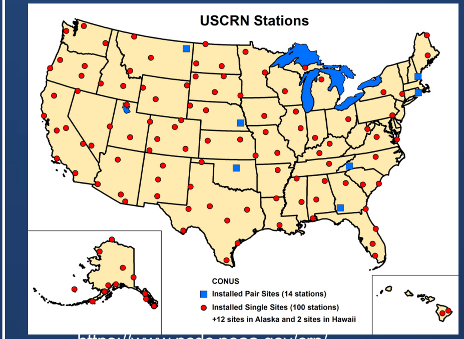


Figure: D. Entekhabi, MIT

"Traditional" Approach

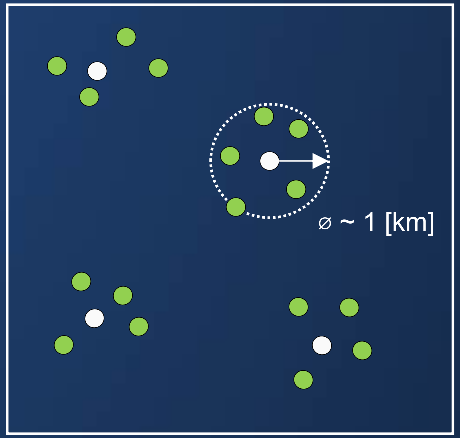


Single Soil Moisture station



https://www.ncdc.noaa.gov/crn/

Wireless Sensor Networks (WSN)



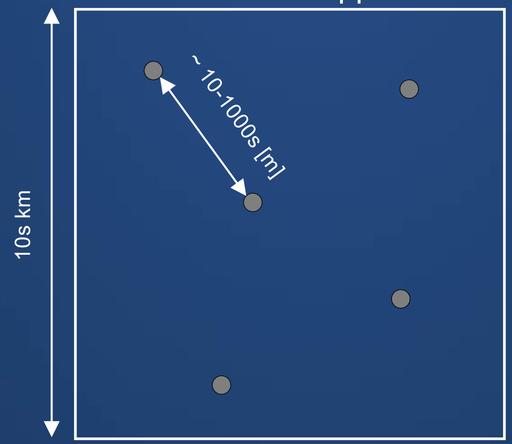
WSN Cluster (< 20 Nodes)

Example Sites in CA and AZ

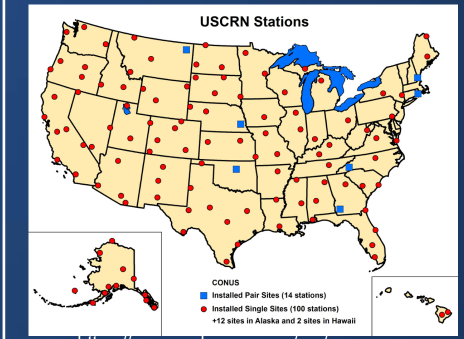
Technology Solution:

1. UAVs are mobile platforms which can “gap fill” (and complement) WSNs.
2. Software Defined Radars (SDRadars) have reached a level of maturity that can map local soil moisture (100s [m])
3. The technical challenge is coordinating WSN and UAV-SDRadar operations.

“Traditional” Approach



Single Soil Moisture station



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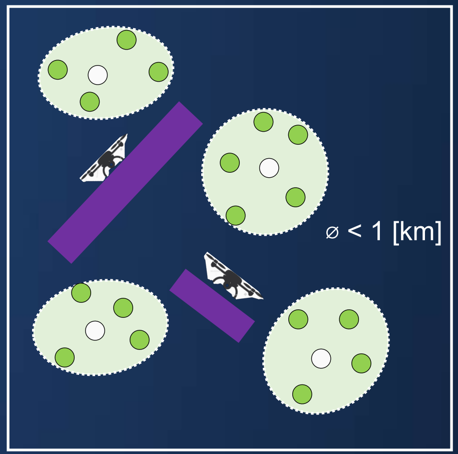
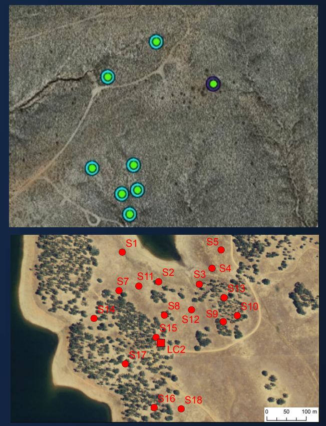
Wireless Sensor Networks (WSN)



WSN Cluster (< 30 Nodes) UAV Flight Path

Example Sites in CA and AZ



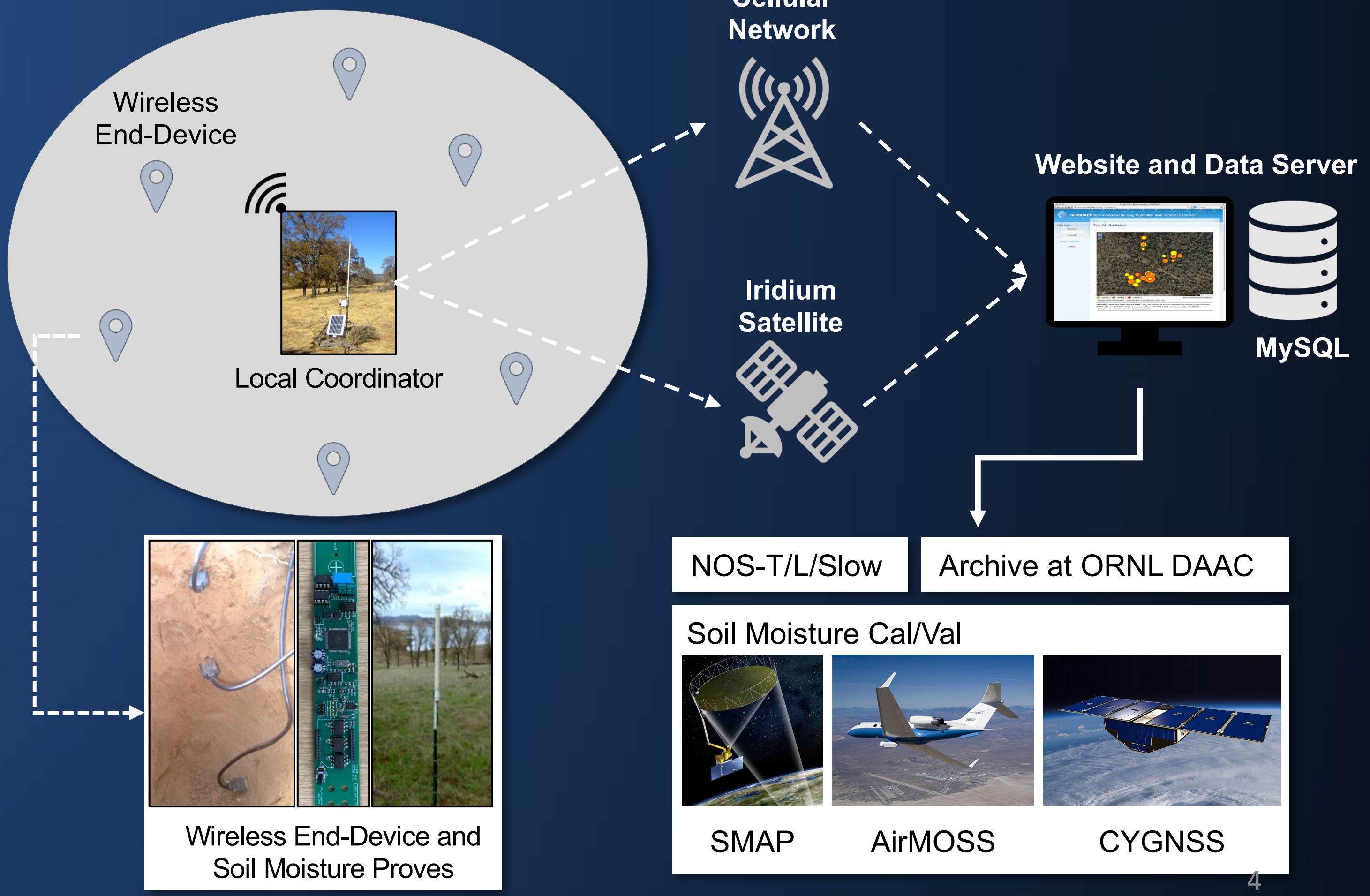
Objective 1: Develop and demonstrate integrated operations between in-situ WSN and networks of UAV-SDRadars

Objective 2: UAV-SDRadar path planning and scheduling methods based on in-situ WSN soil moisture measurements

SoilSCAPE Wireless Soil Moisture Sensor Networks (TRL-7)

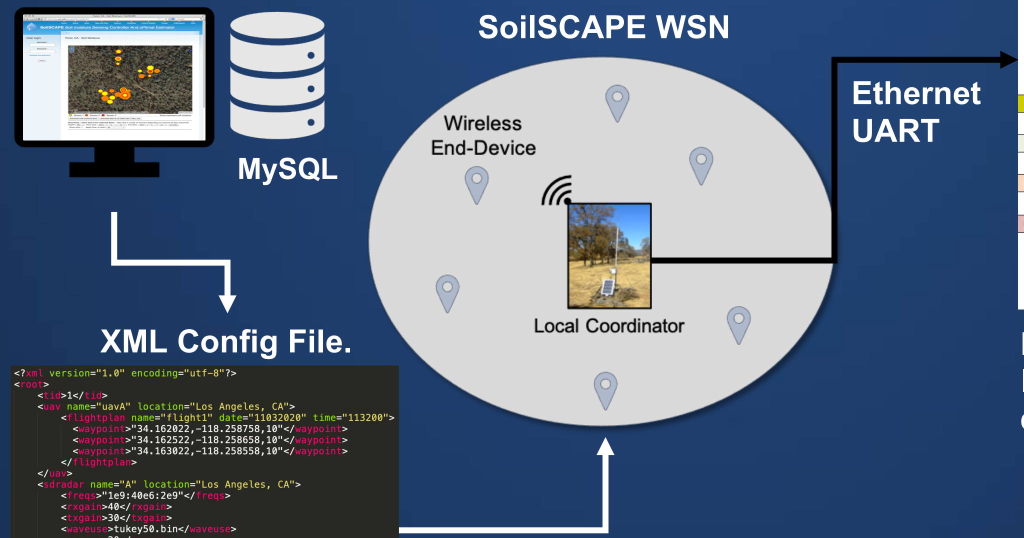
- Clusters of medium-scale (~1 [km]) *in situ* (WSN)
- Measure and report near real-time surface-to-root zone soil moisture (top 5 [cm] – 100 [cm])
- SoilSCAPE primary objectives:
  - Advancement in low-power wireless sensing technologies
  - Ground truth soil moisture for NASA Earth Science missions
- Implementation
  - Custom made low-power “wireless dataloggers”
  - Wireless network commutation protocols and data-delivery via, e.g., Digi Xbee 900 MHz + 4G/Iridium

SoilSCAPE WSN Architecture and Overview



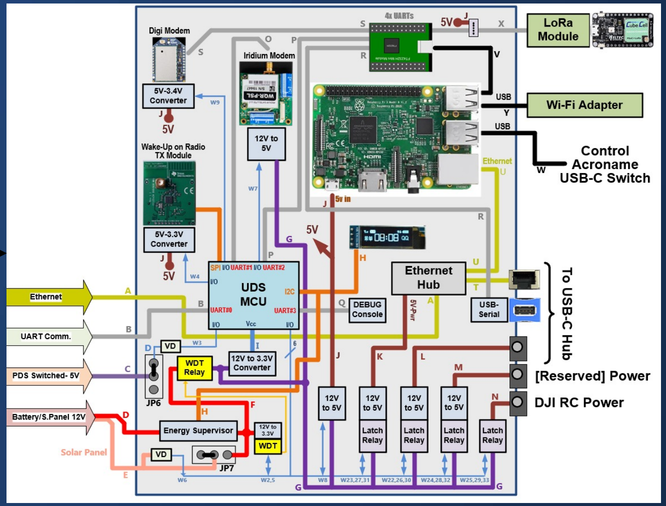
SPCTOR: SoilSCAPE + UAVs

- Custom interface board required to connect SoilSCAPE LC to UAV Manifold
  - Remote switch to power UAV on/off
- XML-like UAV config. file includes SDRadar setting and flight path (GPS way-points)
- Software configurable to handle two-way data and message passing between LC, UAV, and data server



XML Config File.

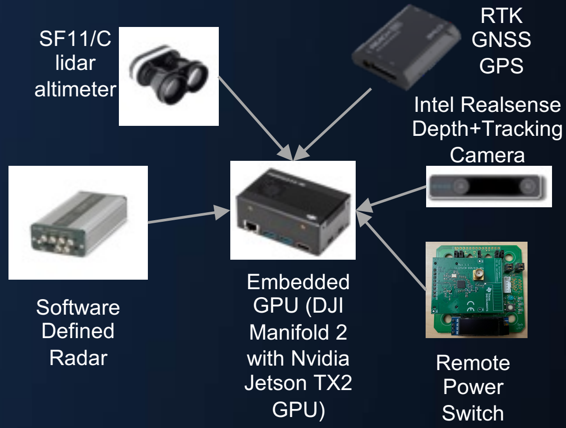
```xml
<?xml version="1.0" encoding="utf-8"?>
<root>
    <tid>1</tid>
    <uav name="uavA" location="Los Angeles, CA">
        <flightplan name="flight1" date="11032020" time="113200">
          <waypoint>"34.162022,-118.258758,10"</waypoint>
          <waypoint>"34.162522,-118.258658,10"</waypoint>
          <waypoint>"34.163022,-118.258558,10"</waypoint>
        </flightplan>
    </uav>
    <sdradar name="A" location="Los Angeles, CA">
        <freqs>"1e9:40e6:2e9"</freqs>
        <rxgain>40</rxgain>
        <txgain>30</txgain>
        <waveuse>tukey50.bin</waveuse>
        <sweeps>20</sweeps>
        <sri>1</sri>
        <num>10</num>
        <avg></avg>
        <secfuture>.001</secfuture>
        <pri>3e-4</pri>
        <fdxcal>0</fdxcal>
        <fastfreqhop>1</fastfreqhop>
        <cals>0</cals>
        <numcal>10</numcal>
        <file>spctor_uavsdradar_demo/out.dat</file>
        <notransfer></notransfer>
    </sdradar>
</root>
```



Connectivity to UAV: Digi Xbee, WIFI, USB

LC-UAV Interface Board
Includes Wakeup-on-Radio technology developed during prior AIST-16 project

Next Generation UAV-SDRadar sensor payload

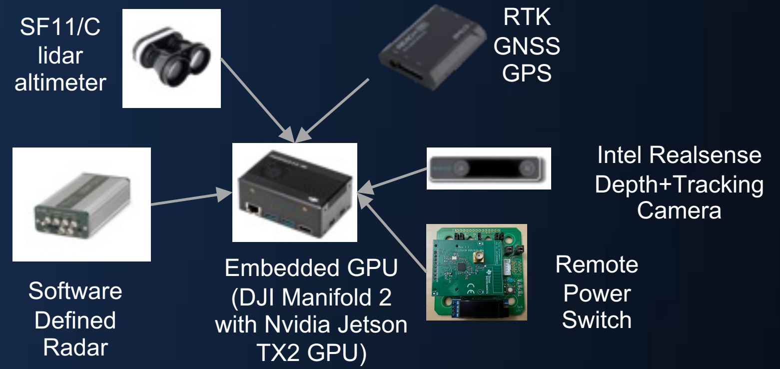


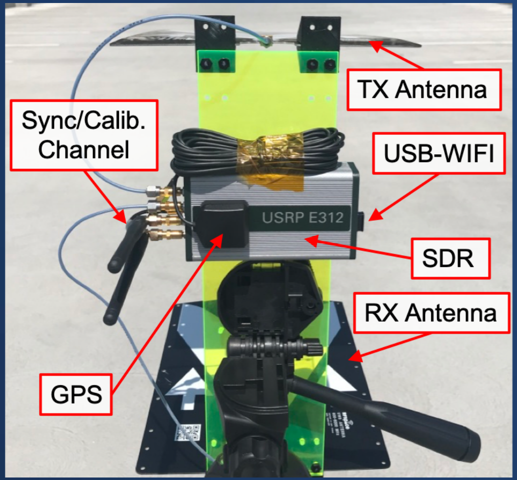
SPCTOR: SoilSCAPE + UAVs

UAV with Software Defined Radar (SDRadar) Payload*

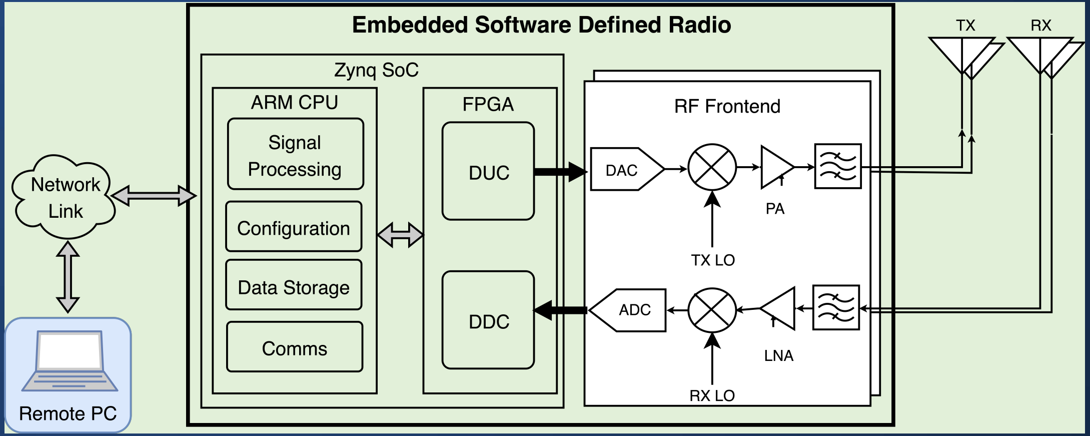
- Single radar sensor that can be deployed across a wide range of environments with different characteristics and requirements
- Small, low-cost, and highly flexible hardware platform
- Real-time configuration and control
- *Potential to perform environmental monitoring tasks at higher spatial and temporal resolutions than space-borne counterparts and with larger area coverage than in-situ sensors*

Next generation UAV-SDRadar sensor payload





USC SDRadar prototype built using USRP E312 hardware



* See ESTF presentation on 06/24: *Ground Penetrating Radar (GPR) Soil Moisture Integration* – Mahta Moghaddam, USC

UAV Path Planning for Soil Moisture Mapping

ESTF2021

- In situ WSN soil moisture input to *Gaussian Process Regression* model to generate "uncertainty map", u_{ij}
  - Soil moisture upscaling models have high confidence close to sensor nodes
  - Models degrade further away from sensor locations

- Mixed Integer Programming (MIP) to maximize UAV round-trip flight over soil moisture uncertainty map*

$$\max \sum_{i,j}^{N} u_{ij} \cdot x_{ij} \ ; \quad x_{ij} \in \{0,1\}$$

- Off-line MIP solver yields GPS ways points for UAV-SDRadar
- Can generate one or more distinct paths, e.g., TSP-like and VRP-like solutions
  - UAV range constraint by payload mass, and velocity by SDRadar settings (BW, range and azimuth resolutions)

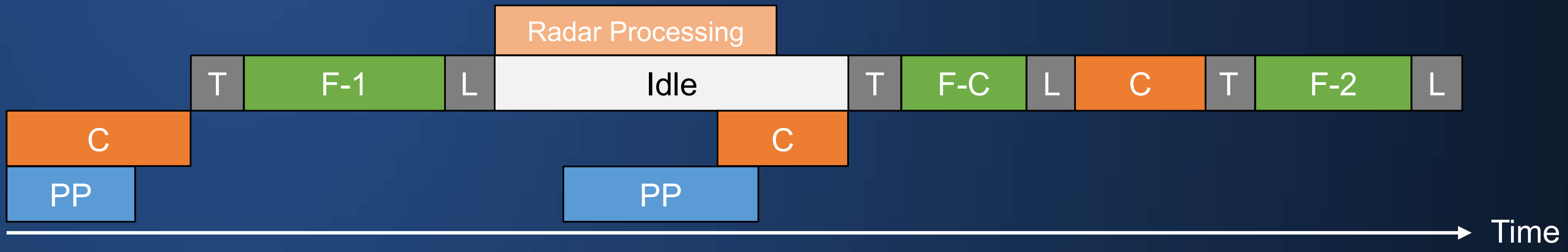
Play button here:

* Akbar, R., Prager, S., Silva, A., Moghaddam, M., Entekhabi, D., "Wireless Sensor Network Informed UAV-SDRadar Path Planning for Soil Moisture Mapping." in IEEE Transactions on Geoscience and Remote Sensing, *in Press*.

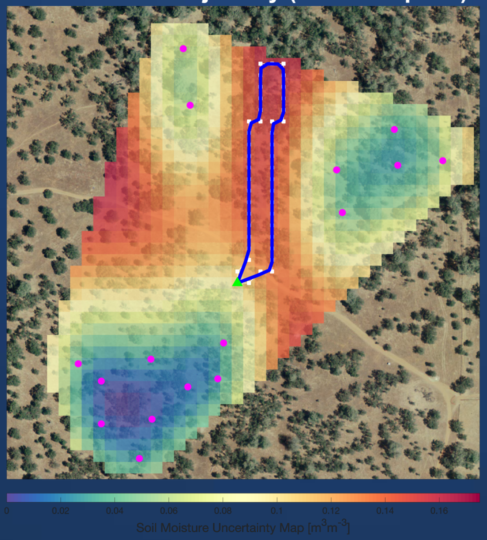
UAV Path Planning for Soil Moisture Mapping

“Activity Planning”

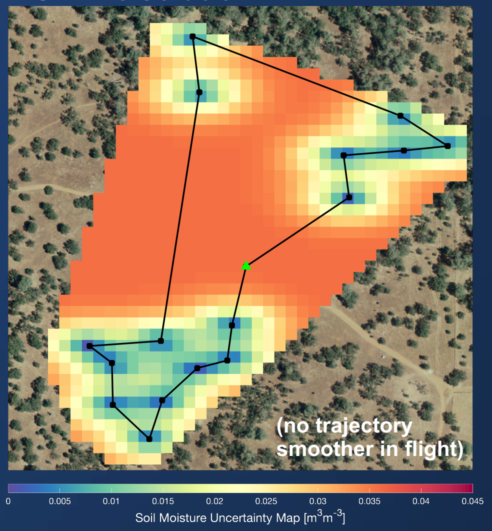
- Arrange daily activity “timeline” to execute UAV commands
- Charging (C), take-off and landing (T, L) , Path Planning (PP), Flights (F-1), etc.
- Currently investigating optimization-based activity planning for multiple UAVs



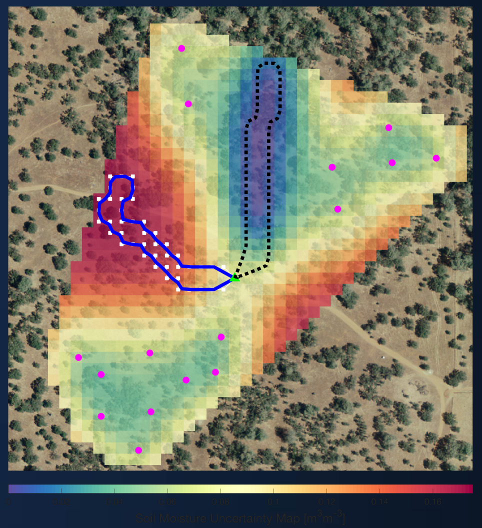
F-1 Flight
Line: Smooth Trajectory (cubic B-spline)



Calibration Flights (F-C)
TSP-like solution



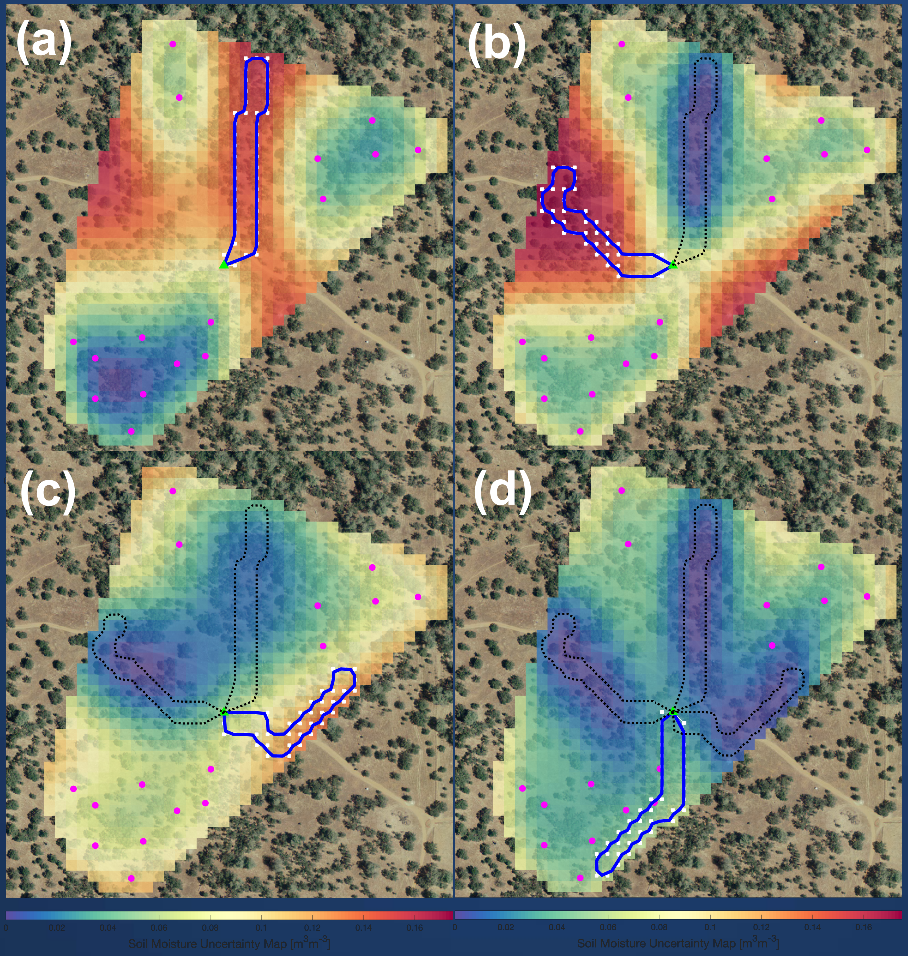
F-2 Flight
Previous flight’s radar data updates uncertainty map

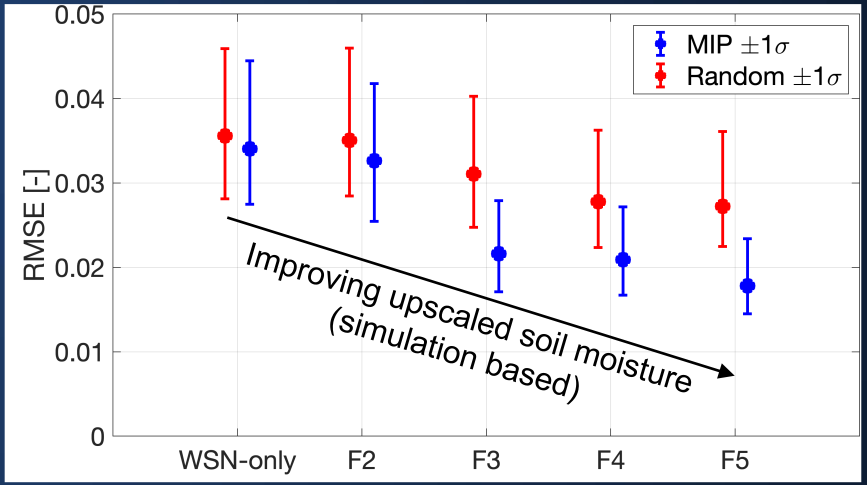


UAV Path Planning for Soil Moisture Mapping

“Recursive Soil Moisture Mapping”

- Improve upscaled soil moisture estimated by recursively flying UAV and mapping soil moisture
- Previous SDRadar soil moisture integrated into Gaussian Process Regression model to generate new flight paths

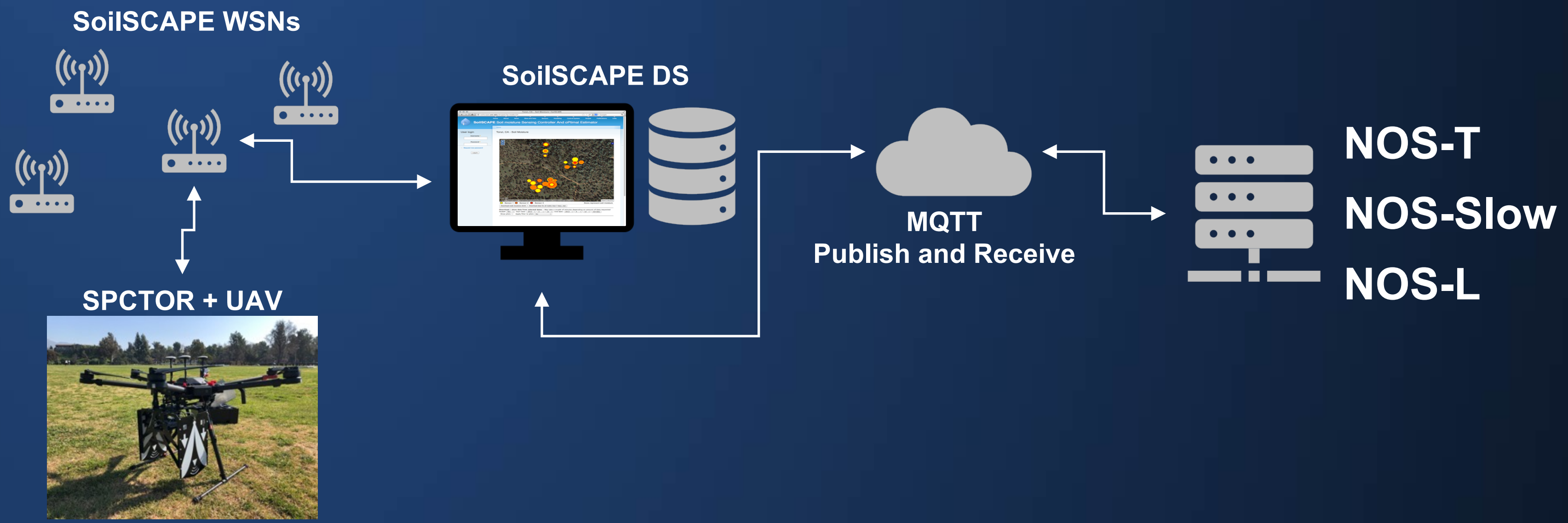




- **Field activities planned for summer 2021**
- **Demo end-to-end path planning and UAV autonomous fights**

SPCTOR, SoilSCAPE, and Contributions to NOS

- NOS Testbed (NOS-T) Flood mapping Demo
  - Participated in developing NOS-T and feasibility demo as the “soil moisture node”
- Developing Near real-time upscaled soil moisture for NOS-Slow testbed expansion
- On-going/future contributions:
  - Integration of SoilSCAPE in situ WSNs in to NOS and real-time soil moisture delivery
  - SPCTOR + UAV flight planning and execution from NOS triggers



Related ESTF presentation on 06/24:
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